



VU Research Portal

Preliminary monetary values for the reliability of travel times in freight transport

de Jong, G.; Kouwenhoven, M.; Kroes, E.P.; Rietveld, P.; Warffemius, P.

published in

European Journal of Transport and Infrastructure Research
2009

document version

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

citation for published version (APA)

de Jong, G., Kouwenhoven, M., Kroes, E. P., Rietveld, P., & Warffemius, P. (2009). Preliminary monetary values for the reliability of travel times in freight transport. *European Journal of Transport and Infrastructure Research*, 9(2), 83-99.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:

vuresearchportal.ub@vu.nl

Preliminary Monetary Values for the Reliability of Travel Times in Freight Transport

Gerard de Jong

Significance¹

Institute for Transport Studies, University of Leeds, and NEA

Marco Kouwenhoven

Significance²

Eric Kroes

Significance³

VU University Amsterdam

Piet Rietveld

VU University Amsterdam⁴

Pim Warffemius

KiM Netherlands Institute for Transport Policy Analysis, Dutch Ministry of Transport, Public Works and Water Management⁵

Received November 2006; accepted November 2008

In The Netherlands, major infrastructure projects are assessed using cost-benefit analysis, following official guidelines. Until recently, the reliability of travel times could not be included in the cost-benefit analysis, because the corresponding monetary valuation was unknown. In recent years, the literature on valuing reliability of travel times was reviewed for the Dutch transport ministry. The outcomes of this were discussed at an expert workshop, which led to an agreement on preliminary monetary values for passenger transport. A key concept is that of the reliability ratio. This is defined as the value of reliability (measured as the standard deviation of travel time) divided by the value of travel time itself. For freight transport a follow-up study was carried out, which transforms the results of earlier stated preference research into a reliability ratio. The paper presents and explains the preliminary values, focussing on the derivation of reliability values for freight transport. It also describes how these values can be used in practical project evaluations.

Keywords: cost-benefit analysis; monetary value; reliability; reliability ratio; travel time

¹ Koninginnegracht 23, 2514 AB The Hague, The Netherlands, T: +31703121533, F: +31703121531, E: dejong@significance.nl

² Koninginnegracht 23, 2514 AB The Hague, The Netherlands, T: +31703121544, F: +31703121531, E: kouwenhoven@significance.nl

³ Koninginnegracht 23, 2514 AB The Hague, The Netherlands, T: +3170 3121532, F: +31703121531, E: kroes@significance.nl

⁴ De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands, T: +31205986097, F: +31703121531, E: prietveld@feweb.vu.nl

⁵ P.O. Box 20901, 2500 EX The Hague, The Netherlands, T: +31703511991, F: +31703517576, E: pim.warffemius@minvenw.nl

1. Introduction

Changes in the reliability of travel time are not incorporated in standard appraisals of infrastructure projects and transport policies in The Netherlands or in other countries. Nevertheless, many transport projects and policies will affect not only the average travel time, but also its spread. There are some indications that travellers, shippers and carriers have substantial valuations for changes in the reliability of transport time.

In 2004, RAND Europe performed a literature review on the value of reliability for the AVV Transport Research Centre (now DVS) of the Dutch Ministry of Transport, Public Works and Water Management (RAND Europe, 2004a, de Jong et al., 2004a). This review showed that studies have been carried out in several countries that yield values in money units or time units for the reliability of travel times for specific cases (for example for passenger transport: (Bates et al., 2001, Brownstone and Small, 2002, Copley et al., 2002, Eliasson, 2004, Hensher, 2007, Hollander, 2005, König, 2004, Liu and Polak, 2007, MVA, 1996, Rietveld et al., 2001); for freight transport: (Bogers and van Zuylen, 2004, 2005, Bruzelius, 2001, Fowkes et al., 2001, Hensher, forthcoming, et al., 2007, de Jong et al., 2004b)). However, no generally accepted monetary values for reliability (or other aspects of quality) were found that are used in official national cost-benefit analyses. But the possibilities of establishing such values are being investigated in some countries (In Europe, besides in the Netherlands also in the United Kingdom and Sweden). A committee for the UK Department for Transport (SACTRA, 1999), came to the conclusion that by ignoring travel time variability the economic benefits of trunk road schemes were underestimated by 5-50%. This concerns the effect of transport projects on reliability of travel times and the value of reliability. The importance of reliability of travel time was also stressed in the Eddington report in the UK (Eddington, 2006).

Many Dutch infrastructure projects in the near future will focus on decreasing the average travel time, as well as on improving the reliability of travel time. Travel time benefits are included in the cost-benefit analysis of such projects by using values of time, which contain expected delays. Unexpected delays were not included since reliability values on these were missing. The lack of values of reliability (VoRs) therefore seriously hampers the relevance of current cost-benefit analysis in this policy area. For this reason, AVV commissioned RAND Europe to convene an expert consultation, in the form of a workshop, to discuss the options regarding preliminary and provisional VoRs, with the aim to use these values in the current cost-benefit framework until more evidence-based values for the Netherlands can be established. This workshop did not reach conclusions on VoRs in freight transport. Therefore, a special investigation was carried out to derive these from the outcomes of an earlier Stated Preference model.

In section 2 of this paper, the policy background is provided. Section 3 briefly presents the outcomes of the expert workshop. The work on the value of reliability in freight transport is described in section 4. In section 5 we give an example of how to apply the values in practice. Section 6 contains the conclusions and recommendations.

2. Time valuation and cost-benefit analysis in the Netherlands

In the year 2000 the Dutch guideline on cost-benefit analysis (CBA) for infrastructure projects (the so called "OEI-guideline") was published (CPB and NEI, 2000). This is the Dutch standard appraisal method for transport projects. According to this guideline, a CBA must be carried out for large governmental infrastructure projects. The CBA serves as a framework for a transparent description of the economic and social effects of the project. In the CBA all effects of an investment project are systematically evaluated and, when possible, given a monetary value. The result is a profitability analysis. CBA information is useful in almost every stage of policy preparation to facilitate decision-making.

The OEI-guideline was evaluated in 2002. Overall, it was seen to function well but it appeared that some aspects of the method needed further elaboration. Therefore, the Dutch Ministry of Transport, Public Works and Water Management together with the Dutch Ministry of Economic Affairs, started a research program. In December 2004, the results were published in the form of appendices to the OEI-guideline. An important issue discussed in these appendices is the monetary value of reliability of travel times.

Currently, benefits from improved reliability are not included in the standard Dutch CBA-framework for appraisal of infrastructure projects. In other words, the current Values of Time (VoT) of the OEI-guideline are only related to reductions in the *average* travel time. The average travel time includes expected delays.

Unexpected delays however, appear much less systematic and lead to variation in travel times. Unexpected delays may be caused by congestion and other factors such as bad weather, accidents, vehicle break-downs or unreliability of public transport modes. We can distinguish two forms of unexpected delays (Ritsema et al., 2004). On the one hand there is the random day-to-day variability that could affect the travel time for journeys undertaken at the same time each day. On the other hand there are the occasional catastrophic delays as a result of incidents.

Unexpected delays in passenger transport generate costs because of: prolonged waiting times, stress among travellers, connections missed, appointments missed, negative effects on business efficiency. Most attention is typically given to arriving too late. However, arriving too early also generates costs, for example: waiting at the destination for your appointment. Unexpected delays in freight transport may lead to:

- Greater than expected decline in the value of the goods (especially important for perishable goods) and capital tied up in the goods longer than was anticipated;
- Missed connections at transshipment points;
- Waiting time for staff at the receiving end, or even missing out on the delivery window and having to deliver again at the next delivery interval;
- Missed opportunities for applying JiT (Just-in-Time) to physical distribution, production (delays leading to disruption of the production process, because of unavailability of critical inputs), and the management of stocks (a more reliable transport system can make it possible to reduce inventories and use fewer warehouses and distribution centres) .

In Figure 1, the expected delay is included together with the free-flow travel time in the expected travel time. In contemplating a journey, the driver not only considers this (expected) average travel time but also its variability, which can be quantified by the standard deviation of the travel time distribution (also see Figure 1). If the driver wants to reduce the risk of being late at his destination, he or she will need to allow rather more time than the mean travel time (the so called safety margin).

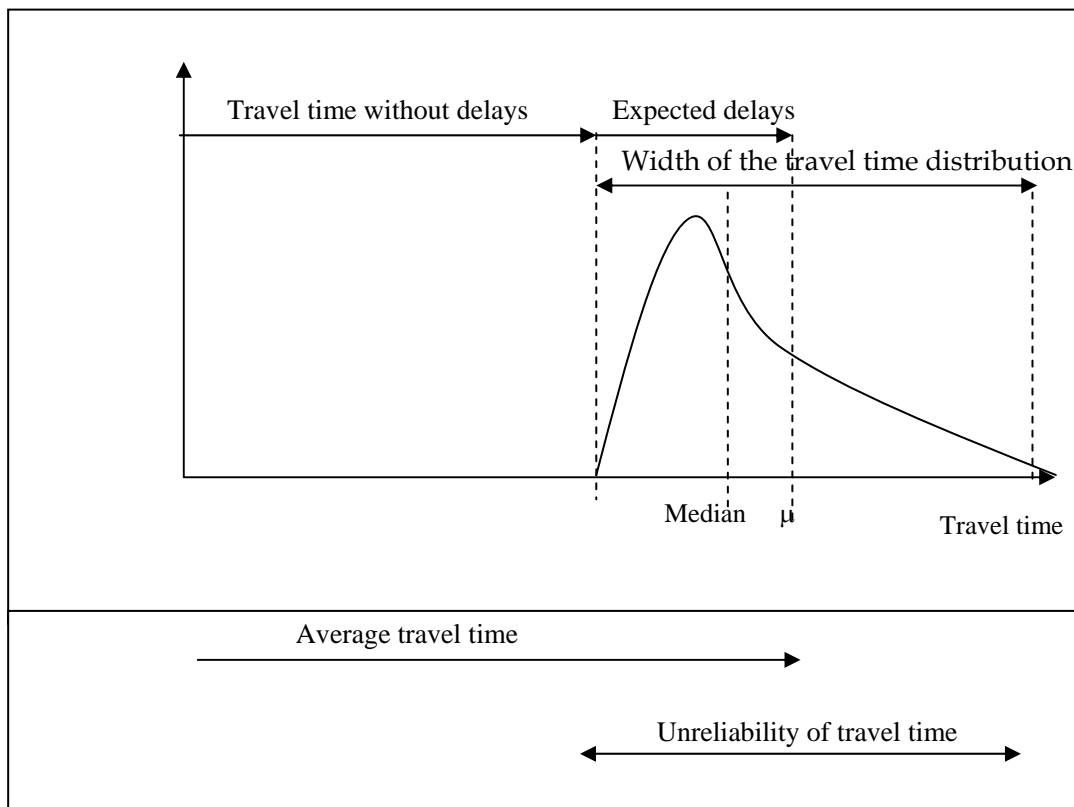


Figure 1. Travel time distribution

Note: The wider (longer tailed) the travel time distribution, the more unreliable travel time is considered.

Source: Dutch Ministry of Transport, Public Works and Water Management and Dutch Ministry of Economic Affairs, 2004.

As mentioned above, the current VoTs of the OEI-guideline are related to reductions in the average travel time only. However, in the near future many Dutch infrastructure projects will focus explicitly on reliability of travel times. It is expected that benefits of this improved reliability will be of substantial importance in comparison to benefits of reductions of the average travel time. Therefore it is important to find monetary values for reliability of travel times that can be used in CBA.

3. Results of expert workshop

The Workshop 'Value of Reliability' took place on 25 October 2004. It was an initiative of the AVV Transport Research Centre of the Dutch Ministry of Transport, Public Works and Water Management, and it was organised by RAND Europe. The aim of the workshop was to provide reasonable *provisional* values of reliability (VoR) for a range of modes or mode-purpose combinations that can be included in the OEI-guideline.

Within the workshop the focus was on valuation of the *unexpected delays* in travel time, preferably expressed as the *standard deviation* from the mean. While this definition has its limitations, using this definition would seem to lead to fewer ambiguities within the current cost-benefit framework.

A secondary aim of the workshop was to discuss ways to address the lack of sufficient studies with regard to VoRs for the various modes and purposes and explore options for international cooperation in addressing the research into evidence based monetary values for reliability.

Participants were invited, not only from The Netherlands, but also from the United Kingdom and Sweden, as reliability of travel time is an issue of growing concern and research in these countries. There are countries outside Europe (e.g. United States, Australia), where this issue is studied as well, but the higher travel cost precluded inviting experts from these countries to the workshop.

The VoRs presented below are based on the opinions of the experts and the discussions during the workshop. We stress that the VoRs are provisional values. To get evidence-based monetary values for reliability, a nationally representative stated preference study among car drivers, public transport users, carriers and shippers is now underway in The Netherlands. Practically all the empirical work that has been done to obtain values for variability has been based on Stated Preference (SP) data. It is generally very hard to collect Revealed Preference (RP) data that includes measures of variability, travel time and travel costs that will not be heavily correlated. Also, with RP data, there is the perennial difficulty of getting information on the attributes of the non-chosen alternatives, e.g. on the travel times at different moments (periods) in time.

The approach to measure the VoR for passenger transport by car consists of the following steps:

- improved reliability of travel times is equal to reductions in travel time variability and thus to reductions in unexpected delays;
- The VoR is defined as the value of a minute of standard deviation of the travel time distribution;
- In the workshop, the experts agreed that the VoR is usually transformed into the Reliability Ratio:

$$\text{VoR} = \text{RR} * \text{VoT}.$$

where:

VoR= value of one minute of standard deviation.

VoT= value of one minute of average travel time.

RR= Reliability Ratio (=VoR/VoT).

The basis for the agreement rested mostly on this being common practice: a convenient transformation since VoTs are usually available (and one wants to be consistent with these).

For passenger transport by car and public transport, the experts agreed on the following reliability ratios (based on the available international evidence, especially from the UK, The Netherlands and Sweden):

Table 1. Reliability Ratios for passenger transport by mode (purposes: commuting, business and other)

Mode	Reliability Ratio
Car	0.8
Train (interurban)	1.4
Bus, tram, metro (urban)	1.4

Source: RAND Europe, 2004d

The reliability ratios in Table 1 do not vary between travel purposes, but the fact that the VoTs vary means that the same variation will be carried over to the VoRs.

With regard to the application and dimensions of the VoRs for freight transport there was no consensus, nor even a majority position within the expert group. All experts agreed that much more research is necessary to establish VoRs for freight transport, in order to validate the obtained results of the Dutch study (RAND Europe, 2004b).

Meanwhile, values from RAND Europe (2004b) will be applied as the best available estimate, but these need to be re-dimensioned into reliability ratios first. In RAND Europe (2004b), the VoRs are measured through the scheduling method (that is relative to agreed delivery time). The research to convert these outcomes into reliability ratios for freight transport is reported in the following section of this paper.

4. Reliability ratios for freight transport

4.1 The general approach

In 2003/2004, RAND Europe together with SEO and Veldkamp/NIPO carried out a study into the value of time in freight transport in The Netherlands (RAND Europe et al., 2004b). This study was commissioned by AVV and comprised revealed preference (RP) and stated preference (SP) information. A discussion on presentation methods for reliability of travel times can be found in Tseng et al. (2007).

On the basis of the SP data, utility functions were estimated per transport (not per tonne) that include transport time (IndexTime: in index numbers, with observed level at 100) and transport costs variables (IndexCost, also indexed), but also a variable Indexprob for the indexed probability of delivering too late (compared to the agreed delivery time or time window):⁶

$$U = \alpha^* \cdot \text{IndexCost} + \beta^* \cdot \text{IndexTime} + \delta^* \cdot \text{IndexProb} + \text{other terms} \quad (1)$$

where U denotes utility and α^* , β^* and δ^* are the estimated coefficients.

Because of the use of indices, this functional form is not standard. Most studies use utility functions with absolute travel cost and time. In this study however, such specifications gave considerably fewer significant coefficients.

The aim of the research project in 2005 was to transform the outcomes for the probability of delivering too late into reliability ratios. This would ease application of the results in practical cost-benefit analysis and would ensure consistency with the treatment of reliability in passenger transport (see above). Also, reliability ratios are needed as an input for LMS-BT (a tool to predict future reliability levels, linked to the Dutch national model system for transport).

We use three results from the 2003/2004 study:

1. The estimated coefficients and their t-ratios (as listed in Table 2);
2. The fraction of transports per mode for which timely arrival is not an issue (because there is no agreed delivery time or time window). These are given in Table 3. Here we find that

⁶ Other studies have used other ways to measure uncertainty. In a stated preference study on route choice, Bogers and van Zuylen (2005) used a visual presentation with one favourable travel time once in 10 days, one unfavourable and 8 normal travel times. They found that truck drivers value the unfavourable travel time twice as high as its objective (risk-neutral) worth. Managers of shippers and carriers did not have this relatively higher value for unfavourable travel times. This measure of unreliability cannot easily be transformed into a reliability ratio for the standard deviation or travel time either.

for 35.6% of the road transports on-time delivery is not an issue. Of the remaining 64.4%, 30.4% need to be delivered within a specified time window and 34.0% at a specific time;

3. The respondents were asked to estimate the probability of delivering too late. The median values are in Table 4 . This gives P_0 : the median of the observed distribution of the probability of delivering (arriving) too late.

The index-form specification of the utility function (1) can be transformed into a 'standard' utility function with absolute time and costs:

$$U = \alpha^* \cdot 100 \cdot (K_0 + \Delta K) / K_0 + \beta^* \cdot 100 \cdot (T_0 + \Delta T) / T_0 + \delta^* \cdot 100 \cdot (P_0 + \Delta P) / P_0 + \text{other terms}$$

$$= U_0 + (100 \cdot \alpha^* / K_0) \cdot \Delta K + (100 \cdot \beta^* / T_0) \cdot \Delta T + (100 \cdot \delta^* / P_0) \cdot \Delta P + \text{other terms} \quad (2)$$

Here, K is cost (in euros), T is time (in minutes) and P is the probability of delivering too late. The subscript 0 denotes the reference (base) value and Δ gives the change relative to this reference. The reliability ratio ($RR \equiv \gamma / \beta$) is a concept that is defined for a standard utility function:

$$U = \alpha \cdot K + \beta \cdot T + \gamma \cdot \sigma + \text{other terms}$$

$$= \alpha \cdot (K_0 + \Delta K) + \beta \cdot (T_0 + \Delta T) + \gamma \cdot (\sigma_0 + \Delta \sigma) + \text{other terms}$$

$$= U_0 + \alpha \cdot \Delta K + \beta \cdot \Delta T + \gamma \cdot \Delta \sigma + \text{other terms} \quad (3)$$

Here σ denotes the standard deviation of travel time. So for deriving a reliability ratio for freight transport, the coefficients from the index utility function need to be transformed into 'standard' coefficients:

Table 2. Estimation results from 2003/2004 Dutch freight value of time survey

<i>Segment</i>	<i>Index Cost</i>		<i>Index Time</i>		<i>Index probability not on time</i>	
	α^*	<i>t-ratio</i>	β^*	<i>t-ratio</i>	δ^*	<i>t-ratio</i>
Road transport total	-0.0241	-13.0	-0.0192	-2.8	-0.0060	-6.2
- low value raw materials - solo truck - combination	-0.0307	-10.9	-0.0241	-1.9	-0.0042	-2.9
-high value raw materials - solo truck - combination						
- containers - solo truck - combination						
- final products - with loss of value - small truck - solo truck - combination - without loss of value - small truck - solo truck - combination	-0.0220	-4.4	-0.0176	-2.5	-0.0081	-7.8
Rail - bulk - containers - wagonload						
Inland waterways transport - containers - non-containers						
Sea transport - containers - non-containers						
Air transport						

Source: RAND Europe et al., 2004b

Table 3. Percentage of goods transports that need to deliver on time

	Road (%)	Rail (%)	Inland waterways (%)	Sea (%)	Air (%)
Specific time	34.0	25.0	39.6	38.5	43.8
Time window	30.4	52.8	24.5	26.9	25.0
'On time' is not an issue	35.6	22.2	35.8	34.6	31.3

Source: RAND Europe et al., 2004b

Table 4. Median of the probability of delivering too late

Segment	P ₀
Road	5%
Rail	5%
Inland waterways	3%
Sea	5%
Air	5%

Source: RAND Europe et al., 2004b

$$\alpha = 100 \cdot \alpha^* / K_0$$

$$\beta = 100 \cdot \beta^* / T_0$$

$$\delta = 100 \cdot \delta^* / P_0 \quad (4)$$

The reliability ratio RR is a sort of trade-off ratio between an improvement in travel time and an improvement in the standard deviation of travel time:

$$\gamma / \beta = -\Delta T / \Delta \sigma \mid_{\text{constant utility, cost, other terms}} \equiv \text{RR} \quad (5)$$

The above equation can be derived by taking the total differential of the utility function and setting to zero (keeping utility constant, as well as the other terms), given that the marginal utilities are: $\partial U / \partial \sigma = \gamma$ and $\partial U / \partial T = \beta$.

However, the 2003/2004 study has not produced a direct estimate of the ratio γ / β . It yielded the trade-off ratio between an improvement in the indexed travel time (a percentage change) and the indexed probability of delivering too late (another percentage change):

$$\delta^* / \beta^* = -(\Delta T / T_0) / (\Delta P / P_0) \mid_{\text{constant utility, cost, other terms}} \quad (6)$$

We can derive the reliability ratio from the ratio in (6) as:

$$\begin{aligned} \text{RR} &= -\Delta T / \Delta \sigma = -(\Delta T / \Delta P) \cdot (\Delta P / \Delta \sigma) \\ &= -[(\Delta T / T_0) / (\Delta P / P_0)] \cdot (T_0 / P_0) \cdot (\Delta P / \Delta \sigma) \\ &= (\delta^* / \beta^*) \cdot (T_0 / \sigma_0) \cdot [(\Delta P / P_0) / (\Delta \sigma / \sigma_0)] \end{aligned} \quad (7)$$

So, to calculate the reliability ratio, three factors need to be evaluated:

1. The ratio δ^* / β^*
2. The ratio T_0 / σ_0
3. The ratio $(\Delta P / P_0) / (\Delta \sigma / \sigma_0)$.

4.2 Freight transport by road

In this section we work out the three factors mentioned above, for freight transport by road.

The ratio between the estimated coefficients from the index specification: δ^ / β^* .*

This ratio can be taken directly from the 2003/2004 model estimation results (Table 2):

$$\delta^* / \beta^* = 0.31$$

The ratio between travel time and the standard deviation of the arrival time distribution in the reference situation: T_0 / σ_0 .

There is no information on this from the 2003/2004 freight value of time survey. However, for the development of LMS-BT (RAND Europe, 2004c) travel time has been determined for 154 days in 2002 for 212 (main road network) routes of varying length. This includes both cars and trucks. We revisited this data set and calculated the standard deviations for the different routes. The graph (Figure 2) depicts the travel times and standard deviations for travel time. The straight line gives the mean ratio between these variables. This mean ratio is equal to 3.87.

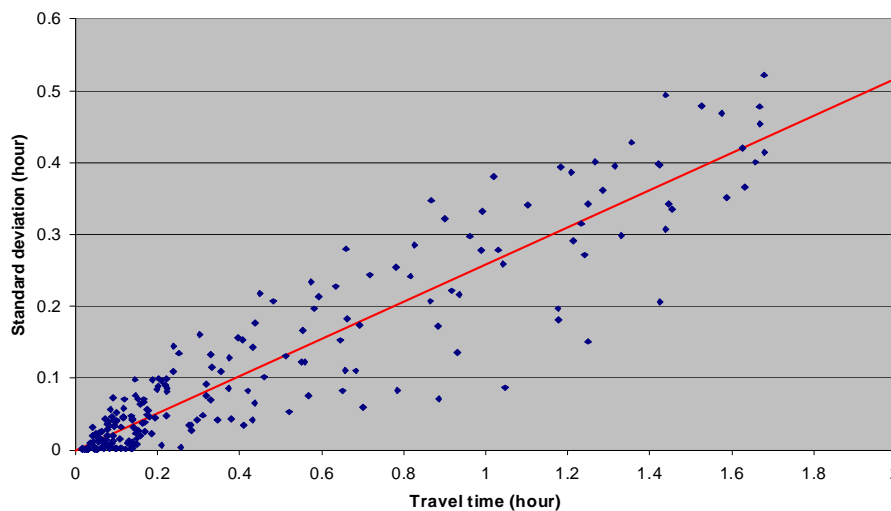


Figure 2. Plot of travel time versus standard deviation of travel time from main road network data
source: RAND Europe, 2004c

Assuming that:

1. the distributions for arrival time and travel time have the same standard deviation;
2. the ratio T_0 / σ_0 for all road freight traffic equals that for the main road network;

we can use this ratio as T_0 / σ_0 in calculating the reliability ratio. These assumptions can be questioned. Trucks have a lower maximum speed than cars and trucks taken together, and usually also a lower average speed. Assumption 2 implies that the standard deviation of travel time will be lower by the same proportion. Also the distances in freight transport are on average longer than for passenger transport and we assume that this does not affect the relative uncertainty.

Probably more important is the assumption on the distributions of arrival times and travel times. In principle the distribution of arrival times is generated by convoluting the distribution of departure times with the distribution of travel times. The spread of the arrival distribution will then be at least as large as that of travel times, but possibly larger, leading to a smaller T_0 / σ_0 . On the other hand in operational delivery scheduling drivers, can compensate travel time benefits and disbenefits by shifting rest times and maybe even by varying speed (e.g. driving faster to make up for time lost), which would increase T_0 / σ_0 . To show the sensitivity with respect to this assumption we have tested a number of values for this ratio (see the next section).

The ratio between percentage changes in P and σ

Under a Normal distribution the probability of delivering too late is:

$$(1 - 2 \cdot P_{\text{TooLate}}) = \text{erf}(BT / (\sigma\sqrt{2})) = \frac{1}{\sigma} \sqrt{\frac{2}{\pi}} \int_0^{BT} \exp\left(-\frac{x^2}{2\sigma^2}\right) dx$$

$$P_{\text{TooLate}} = \frac{1}{2} (1 - \text{erf}(BT / (\sigma\sqrt{2}))) = \frac{1}{2} - \frac{1}{\sigma\sqrt{2\pi}} \int_0^{BT} \exp\left(-\frac{x^2}{2\sigma^2}\right) dx \quad (8)$$

where BT is the buffertime. This is defined as the amount of time between the mean arrival time and the time after which the delivery is too late: on average the carrier arrives earlier than strictly necessary, so that only in a limited number of cases he will be too late. This concept has been introduced by Gaver (1968), who called it 'headstart'. Gaver postulated that if travel time varies, travellers will depart earlier than they would if travel time would be known with certainty: they allow for some slack time to avoid arriving too late. Knight (1974) called this the 'safety margin'.

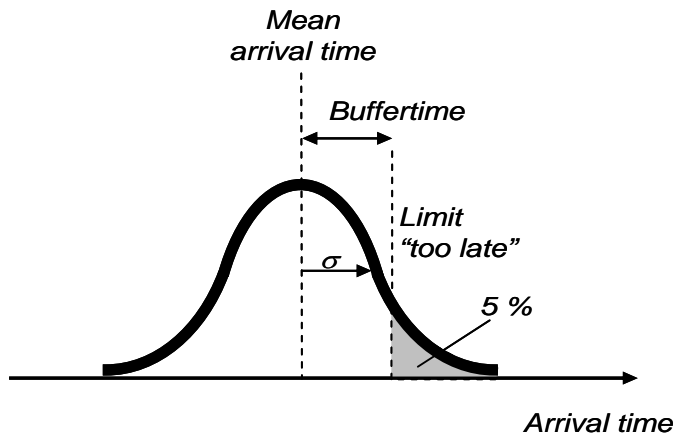


Figure 3. Mean arrival time and buffertime

From the 2003/2004 survey we know that for road transport P_0 is 5%. Then BT_0 is equal to $1.64485\sigma_0$. Now assume that P decreases to 4.95% (relative change of 1%). Then BT is equal to 1.64972σ , or:

$$(BT_0 + \Delta BT) = 1.64972 (\sigma + \Delta\sigma) \quad (9)$$

Until now we have assumed that an improvement in the standard deviation $\Delta\sigma$ (resulting from an infrastructure investment) would lead to a smaller probability of delivering too late (ΔP) and that the buffertime remains constant ($\Delta BT = 0$). This however is only one of many possibilities; one of the extremes in possibility space. The other extreme is that all carriers would react to an improvement in the standard deviation $\Delta\sigma$ by departing later (reducing the buffertime). The latter extreme situation would give a constant probability of delivering too late ($\Delta P = 0$).

Combining all the pieces

We distinguish two extreme situations:

1. If the buffertime would remain constant ($\Delta BT = 0$), the standard deviation must have decreased. The relative change then is:

$$\Delta\sigma / \sigma_0 = 1.64485/1.64972 - 1 = -0.00296 \quad (10)$$

This gives $(\Delta P/P_0) / (\Delta\sigma/\sigma_0) = 3.38$. When we combine this with the results derived earlier we obtain:

$$RR = (\delta^* / \beta^*) \cdot (T_0 / \sigma_0) \cdot [(\Delta P/P_0) / (\Delta\sigma/\sigma_0)]$$

$$= 0.3125 \cdot 3.873 \cdot 3.39 = 4.103. \quad (11)$$

2. If the probability of delivering too late would remain constant ($\Delta P = 0$), the carrier has reacted to the improved standard deviation by reducing the buffertime. Since $BT_0 = 1.64485\sigma_0$ we get $\Delta BT = 1.64485\Delta\sigma$.

The value of having extra buffertime is:

$$\text{Value_extra_buffertime} = \text{VOT} \cdot \text{Trade-off_Buffertimetotraveltime} \cdot \Delta BT \quad (12)$$

As an approximation we use the value of 1 for this trade-off. Then we calculate the equivalent reliability ratio RR_{equiv} at which the value of the extra buffer time is equal to the value of an improvement in the standard deviation

$$\text{VOT} \cdot RR_{\text{equiv}} \cdot \Delta\sigma = \text{VOT} \cdot 1.65\Delta\sigma. \quad (13)$$

Finally we obtain:

$$RR_{\text{equiv}} = 1.65.$$

In practice both processes 1 and 2 will occur simultaneously. The actual reliability ratio will therefore depend on the mix between lateness and reducing the buffer time. If this would be a 50-50 mix, the reliability ratio would be 2.874. Other assumptions for this mix are reported in RAND Europe and Free University Amsterdam (2005). This reliability ratio refers to the part of road freight transport for which delivery on time is an issue. This certainly is the case for the 34.0% of transports that need to arrive at a specified time. From the 2003/2004 survey we calculated that for 9.3% of the road transports the time window was smaller than or equal to the average delay. This gives a total share of road transports that need to be on time of (43.3%). For all road freight transport we therefore get:

$$RR_{\text{final}} = 0.433 \cdot 2.874 = 1.24.$$

This RR of 1.24 for goods transport by road in The Netherlands was derived using a substantial number of assumptions. The value of 1.24 is somewhat larger than what was obtained for cars (0.8), but this is in line with prior expectations. The valuation of travel time itself hardly contains any logistics element. The trade-off ratios between time and costs roughly correspond with the costs for labour and transport vehicles. Disruption of production processes, empty shelves, perishing of commodities, emergency shipments and effects on the safety stock are not (or hardly not) accounted for in the value of travel time. These issues are also more relevant for the value of unexpected delay, and will increase the reliability ratio for freight transport.

4.3 Other modes

The reliability ratio for other transport modes is more difficult to determine, since there is no information that can be used for estimating the ratio between transport time and the standard deviation of arrival time T_0 / σ_0 . Therefore, the reliability ratio was determined for a wide range of assumptions on the ratio between transport time and the standard deviation of arrival time, and on the behaviour of freight carriers. (RAND Europe and Free University Amsterdam, 2005). In this report we have also tested the sensitivity of the reliability ratio for road freight transport for different assumptions on the ratio T_0 / σ_0 and on keeping the buffertime or the probability of

delivering too late constant. Alternative methods have been tried to calculate the reliability ratio for freight transport. However, it turned out that at a minimum the same assumptions had to be made, or that an unrealistic assumption on the distribution of arrival times had to be made.

5. Example of a hypothetical application

In this section we apply the preliminary reliability ratios obtained in the previous sections to demonstrate how these can be used in project appraisal (this is only a demonstration of the principles, not a representative application).

Assume that a major new road project only affects traffic in a corridor. Without the opening of this road link, there would be (according to a transport model) 300,000 persons travelling by car in this corridor on an average working day in 2010 (100,000 commuters, 50,000 business travellers and 150,000 travellers for other purposes). With the new road link this is increased to 330,000 persons (110,000 commuters, 60,000 business, 160,000 other purposes), the increase due to a shift from other modes. On average their travel time is reduced from 60 minutes without the new link to 55 minutes with the link.

Moreover, on an average working day in 2010 there would be 25,000 freight trucks without and 30,000 with the new link. Trucks also have a travel time benefit of 5 minutes on average.

There is also an increase in reliability of travel time: the standard deviation decreases from 15 to 13.75 minutes, both for cars and trucks. Monetary travel costs do not change. For an average working day in 2010, the benefits of the travel time reductions will be calculated as (following the OEI guidelines⁷, in prices of 2004):

Stayers:

Commuters:	$100,000 \times 5 \times (8.70/60)$	=	72,500
Business:	$50,000 \times 5 \times (30.13/60)$	=	125,542
Other:	$150,000 \times 5 \times (6.01/60)$	=	75,125
Freight:	$25,000 \times 5 \times (42.57/60)$	=	88,688

Movers:

Commuters:	$10,000 \times 5 \times 0.5 \times (8.70/60)$	=	3,625
Business:	$10,000 \times 5 \times 0.5 \times (30.13/60)$	=	12,554
Other:	$10,000 \times 5 \times 0.5 \times (6.01/60)$	=	2,504
Freight:	$5,000 \times 5 \times 0.5 \times (42.57/60)$	=	<u>8,869</u>
Time benefits:			389,406

The reliability benefits will be calculated as:

Stayers:

Commuters:	$100,000 \times 1.25 \times 0.8 \times (8.70/60)$	=	14,500
------------	---	---	--------

⁷An alternative way of calculating the benefits for travellers would be to use the change in the logsum from the transport model as the measure of the change in consumer surplus (see de Jong et al. (2005) for a worked-out example).

$$\text{Business:} \quad 50,000 \times 1.25 \times 0.8 \times (30.13/60) = 25,108$$

$$\text{Other:} \quad 150,000 \times 1.25 \times 0.8 \times (6.01/60) = 15,025$$

$$\text{Freight:} \quad 25,000 \times 1.25 \times 1.24 \times (42.57/60) = 27,493$$

Movers:

$$\text{Commuters:} \quad 10,000 \times 1.25 \times 0.5 \times 0.8 \times (8.70/60) = 725$$

$$\text{Business:} \quad 10,000 \times 1.25 \times 0.5 \times 0.8 \times (30.13/60) = 2,511$$

$$\text{Other:} \quad 10,000 \times 1.25 \times 0.5 \times 0.8 \times (6.01/60) = 501$$

$$\text{Freight:} \quad 5,000 \times 1.25 \times 0.5 \times 1.24 \times (42.57/60) = \underline{2,749}$$

$$\text{Reliability benefits:} \quad 88,612$$

Both for time benefits and for reliability benefits we use the rule-of-half for new road traffic. To obtain results on an annual basis, the above numbers need to be multiplied by 285. After that, results for different years might be calculated using a discount rate. In the example, we used a reduction in the standard deviation of 25% of the travel time reduction (both in minutes) to reflect the average ratio between the standard deviation and the travel time in LMS-BT. In these circumstances, taking the reliability benefits into account raises the traveller benefits by 23%⁸.

6. Conclusions and recommendations

6.1 *Passengers*

Until recently, the benefits to travellers of increasing the reliability of travel times could not be included in the cost-benefit analysis of a transport project or policy measure, because the corresponding monetary valuation was lacking. An expert workshop on valuing reliability of travel times led to an agreement on preliminary monetary values for reliability of travel times in passenger transport (both for car and public transport). A key concept here is that of the reliability ratio (RR). This is defined as the value of reliability of travel time divided by the value of travel time itself. Here we measure reliability as the standard deviation of travel time. For car travel, the agreed RR was 0.8, for public transport it was 1.4. The values mentioned are preliminary and can be used until values from new, planned empirical research in The Netherlands will become available.

6.2 *Freight transport*

For freight transport, reliability ratios by mode were derived from earlier Dutch research on the value of time and reliability in freight transport. For freight transport by road, without further information, we recommend to use an RR of 1.24. The values mentioned are preliminary and can be used until values from new, planned empirical research in The Netherlands will become available.

⁸ Apart from travel time, travel costs and reliability changes, other quality attributes of the journey could be incorporated in the traveller benefit calculation: congestion and frequency, interchanges, probability of having a seat in public transport. However, the information on the value of these changes is limited (RAND Europe, 2004a).

6.3 New research

The recommended reliability ratios for passenger transport (especially for car users) are not based on research carried out in the Netherlands. In our opinion, such studies are required to get results that can replace the preliminary values. For freight transport, the large number of assumptions underlying the current (indicative) reliability ratios, leads us to recommend further research in order to derive a more precise reliability ratio.

In The Netherlands, a major empirical study is now underway to measure the value to society of travel time benefits and travel time reliability benefits in passenger and freight transport. This new study is based on a stated preference research, which includes alternatives described by average travel time, average costs, but also the variation of arrival times. This variation will be presented as a series of five to ten arrival times. Furthermore, respondents in freight transport will be asked about arriving late (distinguishing between arriving late due to delays in the production process and due to delays during the transport) and about their buffer time. Finally, it needs to be investigated which fraction of the carriers keep their buffer time constant and which fraction postpones their departure time.

The current values of time might include some elements of the value of unreliability of travel times. These need to be removed to obtain a 'pure' value of time, when the value of reliability is added in project evaluation, to avoid double counting. The new stated preference research therefore is designed in such a way that it can yield both values of time without an unreliability element and reliability ratios.

In order to appraise the reliability effects of infrastructure projects in cost-benefit analyses not only values of reliability are needed but also traffic forecasting models that are able to provide estimates of the changes in the standard deviations of travel times due to the infrastructure improvement projects. Current models typically do not have this capability and significant work is required here.

Acknowledgements

The research reported here was carried out at RAND Europe and the VU University Amsterdam for AVV Transport Research Centre (now DWS) of the Dutch Ministry of Transport, Public Works and Water Management. The authors would like to thank two anonymous reviewers for their very helpful comments.

References

- Bogers, E.A.I. and van Zuylen, H.J. (2004). The importance of reliability in route choices in freight transport. Paper presented at *ETC 2004*, Strasbourg, France.
- Bogers, E.A.I. and van Zuylen, H.J. (2005). De rol van betrouwbaarheid bij routekeuze van vrachtwagenchauffeurs (The importance of reliability in route choices of truck drivers). *Tijdschrift Vervoerwetenschap*, vol. 41, no. 3, pp. 26-30.
- Bates J.J., Polak J., Jones, P. and Cook, A (2001). The valuation of reliability for personal travel. *Transportation Research Part E*, vol. 37, no. 2/3, pp. 191-229.
- Brownstone, D. and Small, K.A. (2002). *Valuing time and reliability: assessing evidence from road pricing demonstrations*. University of California, Irvine.
- Bruzelijs, N. (2001). *The valuation of logistics improvements in CBA of transport investments – a survey*. SAMPLAN, SIKa, Sweden.

Copley, G.P. Murphy and Pearce, D. (2002). Understanding and valuing journey time variability. Paper presented at *European Transport Conference*, Cambridge, UK.

CPB and NEI (2000). *Evaluatie van infrastructuurprojecten: leidraad voor kosten-batenanalyse (Evaluation of infrastructural projects: guide for cost-benefit analysis)*. CPB/NEI, The Hague/Rotterdam.

Dutch Ministry of Transport, Public Works and Water Management and the Dutch Ministry of Economic Affairs (2004). *Aanvulling leidraad OEI-directe effecten (Appendix to the official Dutch guideline for cost-benefit analysis)*. The Hague. (In Dutch).

Eddington, R. (2006). *The Eddington Transport Study: Main Report*. London: HM Treasury.

Eliasson, J. (2004). Car drivers' valuation of travel time variability, unexpected delays and queue driving. Paper presented at *ETC 2004*, Strasbourg, France.

Fowkes, A.S. Firmin, P.E. Whiteing, A.E. and Tweddle, G. (2001). Freight road user valuations of three different aspects of delay. *Proceedings of the European Transport Conference, 2001*, Cambridge, UK.

Gaver, D.P. (1968). Headstart strategies for combating congestion. *Transportation Science*, vol. 2, no.2, pp. 172-181.

Hensher, D.A. Puckett, S.M. and Rose, J.M. (2007). Agency Decision Making in Freight Distribution Chains: Establishing a Parsimonious Empirical Framework from Alternative Behavioural Structures. Paper presented at *the Oslo workshop on valuation*, Oslo, Norway.

Hensher, D.A. (2007). Valuation of Travel Time Savings. In: Lindsey, R., de Palma, A., Quinet, E. And Vickerman, R. (eds.) *Handbook in Transport Economics*. Edward Elgar Publisher, Cheltenham, UK.

Hollander, Y. (2005). The attitudes of bus users to travel time variability. Paper presented at *ETC*, Strasbourg, France.

Jong, G.C. de, Kroes, E.P., Plasmeijer, R., Sanders, P. and Warffemius, P. (2004a). The value of reliability. Paper presented at *ETC 2004*, Strasbourg, France.

Jong, G.C. de, Bakker, S., Pieters, M. and Wortelboer-van Donselaar, P. (2004b). New values of time and reliability in freight transport in The Netherlands. Paper presented at *ETC 2004*, Strasbourg, France.

Jong, G.C. de, Daly, A.J., Pieters, M. and van der Hoorn, A.I.J.M. (2005). The logsum as an evaluation measure, review of the literature and new results. Paper presented at *the 45th Congress of the European Regional Science Association*, Amsterdam, The Netherlands.

Knight, T.E. (1974). An approach to the evaluation of changes in travel unreliability: A "safety margin" hypothesis. *Transportation*, vol.3, no. 4, pp. 393-408.

König, A. (2004). *Messung und Modellierung der Verlässlichkeit des Verkehrsangebots - Experimente mit Schweizer Befragten*. Dissertation, ETH Zürich, Zürich.

Liu, X. and Polak, J.W. (2007). Nonlinearity and Specification of Attitudes Toward Risk in Discrete Choice Models. Paper presented at *the 86th annual meeting of the Transportation Research Board*, Washington DC, USA.

MVA (1996). Benefits of reduced travel time variability. report to DfT; MVA.

RAND Europe (2004a). *De Waardering van kwaliteit en betrouwbaarheid in personen- en goederen vervoer (The valuation of quality and reliability in passenger and freight transport)*. AVV/RAND Europe, Rotterdam, The Netherlands.

RAND Europe, SEO and Veldkamp/NIPO (2004b). *Hoofdonderzoek naar de reistijdwaardering in het goederenvervoer (Main report of the study on the value of time in freight transport)*. Report TR-154-AVV for AVV, RAND Europe, Leiden, The Netherlands.

RAND Europe (2004c). *Ontwikkeling ex ante Instrument Betrouwbaarheid (Development of ex ante reliability tool)*. Report TR-233-AVV for AVV, RAND Europe, Leiden, The Netherlands.

RAND Europe (2004d). *The value of reliability in transport; Provisional values for The Netherlands*. Report TR-240-AVV for AVV, RAND Europe, Leiden, The Netherlands.

RAND Europe and Free University Amsterdam (2005). *Reliability ratio's voor het goederenvervoer (Reliability ratios for freight transport)*. Report for AVV, RAND Europe, Leiden, The Netherlands.

Rietveld, P., Bruinsma, F.R. and van Vuuren, D.J. (2001). Coping with unreliability in public transport chains: A case study for the Netherlands. *Transportation Research A*, vol.35, no. 4, pp.539-559.

Ritsema van Eck, J., Snellen, D. and Hilbers, H. (2004). Travel time reliability: methodology and some results for the Netherlands. Paper presented at *WCTR 2004*, Istanbul, Turkey.

SACTRA (1999). *Transport and the economy: full report. The Standing Advisory Committee on Trunk Road Assessment*, Department for Transport, London, United Kingdom.

Tseng Y., Verhoef, E.T., de Jong, G.C, Kouwenhoven, M. and van der Hoorn, A.I.J.M. (2007). A pilot study into the perception of unreliability of travel time using in-depth interviews. Paper presented at *ETC 2007*, Noordwijkerhout, The Netherlands.

Appendix 1. Participants in the expert workshop in the value of reliability of travel times (including organisers)

From the UK:

John Bates (John Bates Associates)

Geoff Copley (Faber Maunsell)

Chris Smith (UK Department for Transport);

Peter Burge (RAND Europe)

From Sweden:

Jonas Eliasson (Transek)

Inge Vierth (VTI)

From the Netherlands:

Paul Besseling (CPB)

Hans Hilbers (RPB)

Carl Koopmans (SEO, University of Amsterdam)

Wim Korver (TNO-Inro)

Piet Rietveld (Free University Amsterdam)

Wim Spit (Ecorys)

Frank Hofman, Toon van der Hoorn and Pim Warffemius (AVV, now DVS)

Rebecca Hamer, Gerard de Jong Marco Kouwenhoven and Eric Kroes (RAND Europe, now Significance).